ASSESSMENT OF THE PACIFIC COD STOCK IN THE GULF OF ALASKA

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EXECUTIVE SUMMARY

Summary of Major Changes

Relative to the November edition of last year's GOA SAFE report, the following substantive changes have been made in the Pacific cod stock assessment.

Changes in the Input Data

1) Size composition data from the 1997 and January-August 1998 commercial fisheries were incorporated into the model.

Changes in the Assessment Model

There were no changes in the assessment model this year.

Changes in Assessment Results

1) The projected 1999 total age 3+ biomass is 648,000 t, down about 17% from last year's projection for biomass in 1998 and down about 18% from last year's $F_{40\%}$ projection for biomass in 1999.

2) With survey catchability Q and natural mortality M fixed at the conventional values of 1.00 and 0.37, the maximum permissible 1999 ABC is 93,900 t, up about 21% from last year's recommendation for 1998 and up about 1% from last year's $F_{40\%}$ projection for 1999. When uncertainty in Q and M is considered, the risk-averse optimum ABC for 1999 is 90,900 t.

3) The projected 1999 overfishing level is 134,000 t, down about 5% from last year's projection for 1998 and up about 11% from last year's $F_{30\%}$ projection for 1999.

Responses to Comments of the Scientific and Statistical Committee (SSC)

SSC Comments Specific to the Pacific Cod Assessments

From the December, 1997 minutes: *"The SSC encourages continued research and refinement of model processes and evaluation of parameter uncertainty."* Continued research, refinement, and evaluation along the lines suggested by the SSC is described under the headings "Analytic Approach" and "Model Evaluation."

From the October, 1998 minutes: *"The SSC asks the assessment scientist to consider alternative resolutions to the divergence between the prior and likelihood. For example, the ABC calculated under the prior and likelihood model might be calculated separately then averaged, with the separate estimates providing a range."* The SSC's suggested method for calculating ABC is implemented under the heading "ABC Recommendation."

From the October, 1998 minutes: *"In particular the SSC would suggest a plan for analysis of the length-frequency samples used in the catch-at-age calculations be developed.... The sampling might be looked at with respect to a number of factors, in particular the influence of sample size, stratification by fleet sector (gear), time of year and fishing location (statistical area). Is the sampling program adequate? If more fish cannot be measured, should more but smaller samples be taken? Does the spread of samples among the gear-month-area strata lead to biasing the results of the model? What distinctions between the GOA and BSAI suggest different sampling needs for the two areas? How are State of Alaska samples in the GOA entered into the model?"* There has not been sufficient time since the October SSC meeting to develop a plan for analysis of the length-frequency samples used in the catch-at-age calculations. However, as a first step in such an analysis, sample sizes have been tabulated with respect to year, time period, and commercial gear type in Table 2.6; with respect to size bin, time period, and sampling source for the years 1997 and 1998 in Tables 2.7 and 2.8 (pot fishery only); with respect to time period, commercial gear type, and statistical area for the years 1996 and 1997 in Tables 2.9 and 2.10; with respect to year, time period, and size bin for three commercial gear types in Tables 2.11, 2.12, and 2.13; and with respect to year and size bin for the trawl survey in Table 2.14. Sample sizes are discussed under the heading "Commercial Catch Data."

SSC Comments on Assessments in General

The December, 1997 and October, 1998 minutes contain no comments on assessments in general.

INTRODUCTION

Pacific cod (*Gadus macrocephalus*) is a transoceanic species, occurring at depths from shoreline to 500 m. The southern limit of the species' distribution is about 34E N latitude, with a northern limit of about 63E N latitude. Pacific cod is distributed widely over Gulf of Alaska (GOA), as well as the eastern Bering Sea (EBS) and the Aleutian Islands (AI) area. Tagging studies (e.g., Shimada and Kimura 1994) have demonstrated significant migration both within and between the EBS, AI, and GOA, and genetic studies (e.g., Grant et al. 1987) have failed to show significant evidence of stock structure within these areas. Pacific cod is not known to exhibit any special life history characteristics that would require it to be assessed or managed differently from other groundfish stocks in the GOA.

FISHERY

During the two decades prior to passage of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1976, the fishery for Pacific cod in the GOA was small, averaging around 3,000 t per year. Most of the catch during this period was taken by the foreign fleet, whose catches of Pacific cod were usually incidental to directed fisheries for other species. By 1976, catches had increased to 6,800 t. Catches of Pacific cod since 1978 are shown in Table 2.1, broken down by year, fleet sector, and gear type. The foreign fishery peaked in 1981 at a catch of nearly 35,000 t. A small joint venture fishery existed through 1988, averaging a catch of about 1,400 t per year. The domestic fishery increased steadily through 1986, then increased more than three-fold in 1987 to a catch of nearly 31,000 t as the foreign fishery was eliminated. Presently, the Pacific cod stock is exploited by a multiple-gear fishery, including trawl, longline, pot, and jig components. Trawl gear typically accounts for the bulk of the catch (over two-thirds on average since 1986).

The history of acceptable biological catch (ABC) and total allowable catch (TAC) levels is summarized and compared with the time series of aggregate commercial catches in Table 2.2. For the first year of management under the MFCMA (1977), the catch limit for GOA Pacific cod was established at slightly less than the 1976 total reported landings. During the period 1978-1981, catch limits varied between 34,800 and 70,000 t, settling at 60,000 t in 1982. Prior to 1981 these limits were assigned for "fishing years" rather than calendar years. In 1981 the catch limit was raised temporarily to 70,000 t and the fishing year was extended until December 31 to allow for a smooth transition to management based on calendar years, after which the catch limit returned to 60,000 t until 1986, when ABC began to be set on an annual basis. From 1986 (the first year in which an ABC was set) through 1998, TAC averaged about 83% of ABC and aggregate commercial catch averaged about 85% of TAC. In 8 of these 13 years (62%), TAC equaled ABC exactly. In 4 of these 13 years (31%), catch exceeded TAC, and in 2 of these 13 years (16%), catch exceeded ABC as well. Changes in ABC over time are typically attributable to three factors: 1) changes in resource abundance, 2) changes in management strategy, and 3) changes in the stock assessment model. For example, from 1986 through 1998, three different assessment models were used (Table 2.2).

Historically, the majority of the GOA catch has come from the Central regulatory area. The distribution of federally observed hauls or sets in the GOA as well as the EBS and AI (BSAI) is shown for the 1997 trawl, longline, and pot fisheries for Pacific cod in Figures 2.1, 2.2, and 2.3, respectively. To some extent the distribution of effort within the GOA is driven by regulation, as catch limits within this region have been apportioned by area throughout the history of management under the MFCMA. Changes in area-specific allocation between years have usually been traceable to changes in biomass distributions estimated by Alaska Fisheries Science Center trawl surveys or management responses to local concerns. Currently, the allocation follows the biomass distribution estimated by the 1996 trawl survey. The complete history of allocation (in percentage terms) by regulatory area within the GOA is shown below:

Year(s)	Regulatory Area		
	Western	Central	Eastern
1977-1985	28	56	16
1986	40	44	16
1987	27	56	17
1988-1989	19	73	8
1990	33	66	1
1991	33	62	5
1992	37	61	2
1993-1994	33	62	5
1995-1996	29	66	5
1997-1998	35	63	2

The catches shown in Tables 2.1 and 2.2 include estimated discards. Recent (1996) discard rates are summarized in Tables 2.3 and 2.4. Table 2.3 shows species discards in the 1996 Pacific cod fisheries, expressed as percentages of the total catch of all species in those fisheries. Table 2.4 shows discards of Pacific cod in the 1996 fisheries, expressed as percentages of the total area-wide Pacific cod catch. In the GOA, the species category with the highest discard rate in the 1996 Pacific cod fisheries was "miscellaneous groundfish" in the longline fishery, and the fishery with the highest discard rate of Pacific cod was the trawl fishery for shallow-water flatfish.

DATA

This section describes data used in the current assessment. It does not attempt to summarize all available data pertaining to Pacific cod in the GOA.

Commercial Catch Data

Catch Biomass

Catches (including estimated discards) taken in the GOA since 1978 are shown in Table 2.5, broken down by the three main gear types and the following within-year time intervals, or "periods": January-May, June-August, and September-December. This particular division, which was suggested by participants in the BSAI fishery, is intended to reflect actual intra-annual differences in fleet operation (e.g., fishing operations during the spawning period may be different than at other times of year). In years for which estimates of the distribution by gear or period were not available, proxies based on other years' distributions were used.

Catch Size Composition

Fishery size compositions are presently available, by gear, for the years 1978 through the first part of 1998. As in last year's assessment, size composition data from trawl catches sampled on shore were not included in the set of input data, because a comparison of cruises for which both at-sea and shoreside size composition samples were available showed that, in the case of trawl catches, the shoreside data typically contained a smaller proportion of small fish than the at-sea data, indicating that these data may reflect post-discard landings rather than the entire catch. For ease of representation and analysis, length frequency data for Pacific cod can usefully be grouped according to the following set of 25 intervals, or "bins," with the upper and lower boundaries shown in cm:

Bin Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Lower Bound:	9	12	15	18	21	24	27	30	33	36	39	42	45	50	55	60	65	70	75	80	85	90	95	100	105
Upper Bound:	11	14	17	20	23	26	29	32	35	38	41	44	49	54	59	64	69	74	79	84	89	94	99	104	115

The total sample sizes for each year, gear, and period are shown in Table 2.6. Since 1997, the State of Alaska has managed an inshore fishery which uses pot and jig gear only. Both size composition and catch data from this fishery were incorporated into last year's assessment, and the same practice was followed in the present assessment. The SSC has requested that the length samples contributed by the State of Alaska be identified and compared to those contributed by National Marine Fisheries Service (NMFS) observers. This comparison is made for the years 1997 and 1998 in Tables 2.7 and 2.8, which partition the size composition data with respect to size bin, time period, and sampling source (NMFS observer stationed at sea, NMFS observer stationed on shore, or State of Alaska). It should be noted that these data pertain to the pot fishery only, because trawl and longline gears are excluded from the State-managed fishery. The SSC has also requested that sample sizes also be broken down by statistical area. The sample sizes shown in Table 2.6 for the years 1996 and 1997 are therefore subdivided by statistical area in Tables 2.9 and 2.10, respectively (differences between total sample sizes shown in Table 2.6 and the area-partitioned tables may be attributed to the fact that the data used in the former were retrieved on a different date than the data used in the latter and the fact that shore-side observations of trawl size compostions are incuded in the area-partioned tables). Boundaries of the statistical areas referenced in these tables are illustrated in Figure 2.4. It is possible that the distribution of length samples may change in the near future due to a modification of the observer sampling protocol. In general, the modifications are expected to result in fewer cod being measured but a more evenly distributed sample overall (the goal is to obtain lengths from 20 fish of the predominant groundfish species in each sampled haul).

The collections of relative length frequencies are shown, by year, period, and size bin for the trawl fishery in Table 2.11, the longline fishery in Table 2.12, and the pot fishery in Table 2.13.

Trawl Survey Data

The relative size compositions from trawl surveys of the GOA conducted triennially by the Alaska Fisheries Science Center since 1984 are shown in Table 2.14, using the same length bins defined above for the commercial catch size compositions. Total sample sizes are shown below:

Year:	1984	1987	1990	1993	1996
Sample size:	17413	19589	11440	17152	12190

Estimates of total abundance (both in biomass and numbers of fish) obtained from the trawl surveys are shown in Table 2.15, together with the standard errors and upper and lower 95% confidence intervals (CI) for the biomass estimates. The highest biomass ever observed by the survey was the 1984 estimate of 571,188 t, and the low point was the 1990 estimate of 379,494 t. Following the 1984 minimum, increases were observed in both the 1993 and 1996 surveys.

In terms of numbers (as opposed to biomass), the record high was observed in 1996, when the population was estimated to include over 315 million fish. This estimate was more than 90% higher than the previous survey's estimate of 165 million fish.

Length at Age, Weight at Length, and Maturity at Length

Length at age data are few for GOA Pacific cod and are used only sparingly in this assessment. The otoliths which have been read provide the following data regarding the relationship between age and length and the amount of spread around that relationship (lengths are in cm and and ages are back-dated to January 1):

Age group:	3	4	5	6	7	8	9	10	11	12
Average length:	45	52	60	66	74	81	85	90	94	95
St. dev. of length:	2.6	3.5	3.8	4.0	3.9	5.0	6.2	6.9	5.5	7.0

Weight measurements taken by observers over a number of years in the BSAI fishery are used as proxy data for the GOA stock. These data yield the following data regarding average weights (in kg) at length, grouped according to size composition bin (as defined under "Catch Size Composition" above):

Bin number:	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ave. weight:	0.5	0.7	0.8	1.0	1.4	1.6	2.2	2.8	3.7	4.8	5.7	7.0	8.5	9.9	11.5	13.6	15.9

During this year's EBS trawl survey an additional 365 weights were recorded. These new data were not received in time to be incorporated into this year's stock assessment. However, preliminary examination of the new data indicate a weight-length relationship fairly similar to the above.

In 1993, a sampling program was initiated to collect Pacific cod maturity information, using commercial fishery observers. So far, data have been analyzed for 1994 only. These data consist of observers' visual determinations regarding the spawning condition of 2312 females taken in the EBS fishery, which are used as proxy data for the GOA stock. Of these 2312 females, 231 were smaller than 42 cm (the lower boundary of length bin 12). None of these sub-42 cm fish were mature. The observed proportions of mature fish in the remaining length bins, together with the numbers of fish sampled in those length bins, are shown below (bins are defined under "Catch Size Composition" above):

Bin number:	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Prop. mature:	0.03	0.05	0.14	0.19	0.28	0.53	0.69	0.82	0.89	0.94	0.94	0.91	0.89	1.00
Sample size:	39	122	226	313	295	300	320	177	103	70	50	35	19	12

ANALYTIC APPROACH

Model Structure

This year's model structure is identical to the one used in the previous two assessments (Thompson et al. 1996, 1997). Beginning with the 1994 SAFE report (Thompson and Zenger 1994), a length-structured Synthesis model (Methot 1986, 1989, 1990, 1998) has formed the primary analytical tool used to assess the GOA Pacific cod stock. Synthesis is a program that uses the parameters of a set of equations governing the assumed dynamics of the stock (the "model parameters") as surrogates for the parameters of statistical distributions from which the data are assumed to be drawn (the "distribution parameters"), and varies the model parameters systematically in the direction of increasing likelihood until a maximum is reached. The overall likelihood is the product of the likelihoods for each of the model components. Each likelihood component is associated with a set of data assumed to be drawn from statistical distributions of the same general form (e.g., multinomial, lognormal, etc.). Typically, likelihood components are associated with data sets such as catch size (or age) composition, survey size (or age) composition, and survey biomass.

Symbols used in the stock assessment model are listed in Table 2.16 (note that this list applies to the stock assessment model only, and does not include all symbols used in the "Projections and Harvest Alternatives" section of this assessment). Synthesis uses a total of 16 dimensional constants, special values of indices, and special values of continuous variables, all of which are listed on the first page of Table 2.16. The values of these quantities are not estimated statistically, in the strict sense, but are typically set by assumption or as a matter of structural specification. The values of these constants, indices, and variables are listed in Table 2.17, with a brief rationale given for each value used. In contrast to the quantities whose values are specified in Table 2.17, Synthesis uses a large number of parameters that are estimated statistically (though the estimation itself may not necessarily take place within Synthesis). For ease of reference, capital Roman letters are used to designate such "Synthesis parameters," which are listed on the second page of Table 2.16.

Functional representations of population dynamics are given in the Appendix, using the symbols defined on the first two pages of Table 2.16. It should be noted that, while the equations given in the Appendix are generally similar to those used in Synthesis, they may differ in detail. Also, only a subset of the equations actually used by Synthesis is shown. Basically, enough equations are shown to illustrate at least one use for each of the symbols shown on the first two pages of Table 2.16.

As in previous assessments, the present assessment uses Bayesian methods to address uncertainty surrounding the true values of model parameters. Unfortunately, as presently configured, Synthesis is not equipped to handle a full Bayesian analysis. Therefore, a type of meta-analysis is used to implement the Bayesian portion of this assessment (the term "meta-analysis" is used here to denote the fact that this analysis is performed on results obtained from a set of related but technically independent and self-contained primary analyses). The Bayesian meta-analysis exploits the fact that it is sometimes possible (e.g., Walters and Ludwig 1994) to obtain an approximate Bayesian solution by profiling over some subset of the complete parameter set, with all other parameters fixed at their conditional maximum likelihood values (conditional, that is, on the parameter values being considered at any given point in the profile). Although it represents an extreme simplification, the approach used here was to consider the uncertainty surrounding two parameters only, specifically the natural mortality rate *M* and the survey catchability *Q*. The Bayesian meta-analysis, which uses the set of parameters shown on the third page of Table 2.16, proceeds as follows:

1) Assume a bivariate normal prior distribution for *M* and *Q*.

2) Create a large number (thousands) of individual Synthesis models, each based on a unique pair of *M* and *Q* values and each resulting in a conditional maximum log-likelihood and a conditional 1999 ABC (i.e., a conditional 1999 harvest under some specified harvest strategy).

3) Smooth the bivariate log-likelihood profile by regressing a sample of conditional maximum log-likelihood values against *M* and *Q*, assuming a bivariate quadratic relationship. (Even with the simplification afforded by limiting the analysis to uncertainty in *M* and *Q* only, describing the likelihood profile is an extremely difficult task. A requirement for the analysis' success is the ability to determine the maximum value of the log-likelihood function at each combination of *M* and *Q* values included in the profile. However, the log-likelihood function at many, if not all, combinations of *M* and *Q* values can be either very flat or very "ripply," meaning that it is often difficult to be confident that an *apparent* maximum is the *true* maximum. The smoothing procedure was undertaken in an effort to mitigate these problems.)

4) Add an appropriate constant to the smoothed log-likelihood profile so as to result in a rescaled likelihood profile which is proportional to a bivariate normal distribution.

5) Multiply the prior distribution by the rescaled likelihood, then rescale again to yield a bivariate normal posterior distribution.

6) Smooth the bivariate log-ABC profile by regressing a sample of conditional log-ABC values against *M* and *Q*, assuming a bivariate quadratic relationship. (The reasons for smoothing the log-ABC profile are the same as given above in Step 3.)

7) Multiply the posterior distribution by the smoothed log-ABC profile, integrate with respect to *M* and *Q*, then take the antilogarithm of the result to obtain the geometric mean ABC.

The Bayesian meta-analysis provides a context within which the results of any of the thousands of individual Synthesis models described in Step 2 may be viewed. To keep the number of alternative models manageable, however, only three models will be focused upon in the present assessment: Model 1 sets *M* and *Q* equal to the best point estimates that can be obtained independently of the Synthesis models used in the present assessment, estimates which are also used to define the means of the marginal prior distributions for these two parameters. Model 2 sets *M* and *Q* equal to their maximum likelihood estimates. Model 3 sets *M* and *Q* equal to the means of their marginal posterior distributions.

Parameters Estimated Independently

Table 2.18 divides the set of Synthesis parameters into two parts, the first of which lists those parameters that were estimated independently (i.e., outside of Synthesis), and the second of which lists those parameters that were estimated conditionally (i.e., inside of Synthesis). This section describes the estimation of parameters in the first part of Table 2.18.

Natural Mortality

For Model 1, the natural mortality rate was estimated independently of other parameters at a value of 0.37. This value was used in the present assessment for the following reasons: 1) it was derived as the maximum likelihood estimate of M in the 1993 BSAI Pacific cod assessment, 2) it has been used to represent M in all BSAI Pacific cod assessments since 1993 and in all GOA Pacific cod assessments except one since 1994, 3) it was explicitly accepted by the SSC for use as an estimate of M in the GOA Pacific cod assessment (December 1994 SSC minutes, item D-3(b)), and 4) it lies well within the range of previously published estimates of M shown below:

Area	Author	Year	Value
Eastern Bering Sea	Low	1974	0.30-0.45
	Wespestad et al.	1982	0.70
	Bakkala and Wespestad	1985	0.45
	Thompson and Shimada	1990	0.29
	Thompson and Methot	1993	0.37
Gulf of Alaska	Thompson and Zenger	1993	0.27
	Thompson and Zenger	1995	0.50
British Columbia	Ketchen	1964	0.83-0.99
	Fournier	1983	0.65

For Models 2 and 3, the natural mortality rate was not an independently estimated parameter.

Trawl Survey Catchability

For Model 1, the trawl survey catchability coefficient was estimated independently of other parameters at a value of 1.0. This value was used in the present assessment mostly because it had been used in all previous assessments. Also, preliminary results of recent experimental work conducted in the EBS by the Alaska Fisheries Science Center’s Resource Assessment and Conservation Engineering Division tend to confirm that this is a reasonable value (David Somerton, pers. commun.). For Models 2 and 3, the trawl survey catchability coefficient was not an independently estimated parameter.

Weight at Length

Parameters (Table 2.16) governing the relationship between weight and length (Appendix) were estimated by regression from the available data (see “Data” above), giving the following values (weights are in kg, lengths in cm): $W_1 = 5.29 \times 10^{-6}$, $W_2 = 3.206$.

Length at First Age of Survey Observation

Assuming that the first age at which Pacific cod are seen in the trawl survey (a_1) is approximately 1.5 years, the length at this age (L_1) was estimated to be 22.4 cm by averaging the lengths corresponding to the first mode greater than 14 cm (bin 2) from each of the five most recent survey size compositions.

Variability in Length at Age

Parameters (Table 2.16) governing the amount of variability surrounding the length-at-age relationship (Appendix) were estimated by linear regression from the observed standard deviations in the available length-at-age data (see "Data" above), giving the following values (in cm): $X_1 = 1.8$, $X_2 = 6.9$. Estimation of these two parameters constituted the only use of age data in the present assessment.

Maturity at Length

Maximum likelihood estimates of the parameters (Table 2.16) governing the female maturity-at-length schedule (Appendix) were obtained using the method described by Prentice (1976), giving the following values: $P_1 = 0.142$, $P_2 = 67.1$ cm. The variance-covariance matrix of the parameter estimates gave a standard deviation of 0.006 for the estimate of P_1, a standard deviation of 0.39 cm for the estimate of P_2, and a correlation of -0.154 between the estimates of the two parameters.

Parameters of the Joint Prior Distribution of Natural Mortality and Survey Catchability

In addition to the Synthesis parameters discussed above, the Bayesian meta-analysis made use of certain non-Synthesis parameters that were estimated independently, namely the parameters of the joint prior distribution of *Q* and *M*, which consisted of a mean for the marginal distribution of each of the two variables (μ_{Q1} and μ_{M1}), a standard deviation for the marginal distribution of each of the two variables (s_{Q1} and s_{M1}), and a correlation coefficient ($?_1$). The values of these parameters, which have remained constant since their first use in the 1996 assessment, are intended to represent the SSC's collective prior belief regarding the relative plausibility of alternative pairings of *Q* and *M* values. Values of 1.0 and 0.37 were chosen for μ_{Q1} and μ_{M1}, respectively, corresponding to the point estimates of *Q* and *M* used in Model 1. Values of 0.3 and 0.111 were chosen for s_{Q1} and s_{M1}, respectively. These were chosen so as to imply 30% coefficients of variation for both *Q* and *M*. The value of $?_1$ was set at -0.5, representing a compromise between no correlation and a perfect inverse correlation.

Parameters Estimated Conditionally

Those Synthesis parameters that are estimated internally are listed in the second part of Table 2.18. The estimates of these parameters are conditional on each other, as well as on those listed in the first part of the table and discussed in the preceding section (i.e., those Synthesis parameters that are estimated independently).

Likelihood Components

As noted in the "Model Structure" section, Synthesis is a likelihood-based framework for parameter estimation which allows several data components to be considered simultaneously. In this assessment, four fishery size composition likelihood components were included: the period 1 ("early") trawl fishery, the periods 2-3 ("late") trawl fishery, the longline fishery, and the pot fishery. In addition to the fishery size composition components, likelihood components for the size composition and biomass trend from the bottom trawl survey were included in the model. To account for possible differences in selectivity between the mostly foreign (also joint venture) and mostly domestic fisheries, the fishery size composition time series were split into pre-1987 and post-1986 eras.

The Synthesis program allows the modeler to specify "emphasis" factors that determine which components receive the greatest attention during the parameter estimation process. As in the previous two assessments, all components were given an emphasis of 1.0 in the present assessment.

Use of Size Composition Data in Parameter Estimation

Size composition data are assumed to be drawn from a multinomial distribution specific to a particular year, gear/fishery, and time period within the year. In the parameter estimation process, Synthesis weights a given size composition observation (i.e., the size frequency distribution observed in a given year, gear/fishery, and period) according to the emphasis associated with the respective likelihood component and the sample size specified for the multinomial distribution from which the data are assumed to be drawn. In developing the model upon which Synthesis was originally based, Fournier and Archibald (1982) suggested truncating the multinomial sample size at a value of 400 in order to compensate for contingencies which cause the sampling process to depart from the process that gives rise to the multinomial distribution. As in the previous two assessments, the present assessment uses a multinomial sample size equal to the square root of the true sample size, rather than the true sample size itself. Given the true sample sizes observed in the present assessment, this procedure tends to give values somewhat below 400 while still providing the Synthesis program with usable information regarding the appropriate effort to devote to fitting individual samples. Multinomial sample sizes derived by this procedure for the commercial fishery size compositions are shown in Table 2.19. In the case of survey size composition data, the square root assumption was also used, giving the multinomial sample sizes shown below:

Year:	1984	1987	1990	1993	1996
SR(sample size):	132	140	107	131	110

Use of Survey Biomass Data in Parameter Estimation

Each year's survey biomass datum is assumed to be drawn from a lognormal distribution specific to that year. The model's estimate of survey biomass in a given year serves as the geometric mean for that year's lognormal distribution, and the ratio of the survey biomass datum's standard error to the survey biomass datum itself serves as the distribution's coefficient of variation.

MODEL EVALUATION

As discussed under "Model Structure" above, three models are focused upon in this assessment: Model 1 sets *M* and *Q* equal to the best point estimates that can be obtained independently of the Synthesis models used in the present assessment, estimates which are also used to define the means of the marginal prior distributions for these two parameters; Model 2 sets *M* and *Q* equal to their maximum likelihood estimates; and Model 3 sets *M* and *Q* equal to the means of their marginal posterior distributions. (It should be noted that likelihoods were computed on the basis of an input data set that did not include the most recent estimates of 1998 catch. However, informal tests based on an input data set that *did* include the most recent estimates of 1998 catch--i.e., the 1998 catch estimates shown in Table 2.5--showed no appreciable difference.)

Evaluation Criteria

Three criteria will be used to evaluate the three models developed in the present assessment: 1) the effective sample sizes of the size composition data, 2) the root mean squared error (RMSE) of the fit to the survey biomass data, and 3) the overall reasonableness of the parameter estimates.

Effective Sample Size

Once maximum likelihood estimates of the model parameters have been obtained, Synthesis computes an "effective" sample size for the size composition data specific to a particular year, gear/fishery, and time period within the year. The effective sample size can be interpreted as the multinomial sample size that would typically be required in order to produce the given fit. A rule of thumb for viewing a fit as "good" might be based on the relationship between effective sample size and the input sample size (i.e., if effective sample size exceeds the input sample size, the fit is reasonably good). The following table shows the average of the input sample sizes and the average effective sample sizes for each of the size composition components (in each column, the average is computed with respect to all years and periods present in the respective time series):

	Average of Square Root	Average Effective Sample Size		
Likelihood Component	of True Sample Size	Model 1	Model 2	Model 3
Early-season trawl fishery size composition	147	447	349	336
Late-season trawl fishery size composition	42	80	72	72
Longline fishery size composition	111	232	307	297
Pot fishery size composition	93	316	295	298
Survey size composition	124	128	132	133

All three models have average effective samples at least as great as the average input values (the average values of the square roots of the true sample sizes) for all likelihood components. Model 1 has the largest average effective sample sizes for three out of the five components, while Models 2 and 3 each have the largest effective sample size for one of the remaining two. However, it should be noted that all size composition components do not contribute equally to the overall likelihood because of differences in total sample size (i.e., the sum of sample sizes across all years and periods). For example, because the longline fishery (where Model 2 performed best) is associated with many more years' and periods' worth of size composition data than the early-season trawl fishery (where Model 1 performed best), the longline component contributes more to the overall likelihood than does the early-season trawl component.

Fit to Survey Biomass Data

The log-scale RMSEs from the three models' fits to the survey biomass time series are shown below:

Model	RMSE
1	0.211
2	0.250
3	0.212

Model 1 has the lowest survey biomass RMSE, although the RMSE from Model 3 is virtually identical.

Overall Reasonableness of Parameter Estimates

The following table gives the model-specific estimates of length-at-age parameters K and L_2 (L_1 was estimated independently, and thus did not vary with choice of model):

Parameter	Model 1	Model 2	Model 3
K	0.151	0.178	0.174
L_2	84.8	80.7	81.3

The estimates of these two parameters do not vary drastically between models. It may be noted that the estimates of L_2 from all three models are lower than the mean length of age group 12 observed in the available length-at-age data (95 cm).

Model-specific estimates of fishing mortality rates $F_{g,y,i}$, recruitments R_y and initial numbers at age N_a, and selectivity parameters $S_{1\text{-}7,g,e(y*g)}$ are shown in Tables 2.20, 2.21, and 2.22, respectively. In general, Model 1 tends to result in lower estimated fishing mortality rates than Model 2 and higher estimated fishing mortality rates than Model 3. Model 1 tends to produce the highest estimates of recruitment and initial numbers at age, and Model 2 the lowest. Model 1 tends to produce the least sharply domed selectivity curves, and Model 2 the most.

The parameter values associated with the prior distribution, smoothed and rescaled likelihood profile, and posterior distribution in the three alternative models are shown below:

Parameter	Model 1		Model 2		Model 3	
	Label	Value	Label	Value	Label	Value
marginal mean of M	μ_{M1}	0.37	μ_{M2}	0.131	μ_{M3}	0.211
marginal mean of Q	μ_{Q1}	1.00	μ_{Q2}	2.52	μ_{Q3}	1.19
marginal standard deviation of M	s_{M1}	0.111	s_{M2}	0.130	s_{M3}	0.037
marginal standard deviation of Q	s_{Q1}	0.3	s_{Q2}	2.68	s_{Q3}	0.277
correlation between M and Q	$?_1$	-0.5	$?_2$	-0.963	$?_3$	-0.467

The distributions corresponding to the above parameter values are shown in Figure 2.5.

If μ_{M1} and μ_{Q1} (Model 1) are interpreted as the expected values of M and Q prior to performing the assessment, the parameter estimates that describe the smoothed likelihood profile are remarkable because they are so different from $\mu_{M\,1}$ and $\mu_{Q\,1}$, although the 95% confidence intervals of the prior distribution and the likelihood do overlap. While the mode of the posterior distribution (Model 3) falls within this region of overlap, the mode of the prior distribution (Model 1) lies outside the 95% confidence intervals of both the posterior distribution and the likelihood, and the mode of the likelihood (Model 2) lies outside the 95% confidence intervals of both the prior and posterior distributions.

Selection of Final Model

One of the main purposes of stock assessments such as the present one is to provide reference estimates of historic biomass trends, target and limit harvest rates, and biomass projections. It is therefore convenient to choose a single model which can be used to generate a set of such reference estimates. By definition, Model 2 is associated with a higher likelihood than either Model 1 or Model 2. However, as shown by the effective sample sizes associated with the size composition data and the RMSE of the survey biomass estimates, Model 1 and Model 3 perform as well or better than Model 2 in some areas. More importantly, though, the differences between the estimates of *M* and *Q* in Models 2 and 3 (particularly Model 2) with respect to the estimates of *M* and *Q* in Model 1 are so striking as to call into question the significance of any improved fits obtained by Models 2 and 3. It may be noted that Model 1 has served as the baseline model for reporting reference estimates in each of the two most recent assessments. Even though Models 2 and 3 give superior fits to that given by Model 1 by some measures, it is not clear that this constitutes sufficient grounds for abandoning the use of Model 1 as a tool for generating reference estimates. In fact, given the extreme values of *M* (and, to a lesser extent, *Q*) associated with Models 2 and 3, it seems best to retain the use of Model 1 as a tool for generating reference estimates, for the time being at least. Nevertheless, selection of Model 1 for this specific purpose does not have to imply that other models or parameter combinations cannot be considered for other uses, such as recommending an acceptable biological catch for 1999.

Parameter Estimates Associated with the Final Model

The parameter estimates associated with Model 1 are shown in the columns labeled "Model 1" in the preceding section and in Tables 2.20, 2.21, and 2.22. In addition, the parameter estimates listed in the section entitled "Parameters Estimated Independently" also pertain to Model 1.

Schedules Defined by Final Parameter Estimates

Lengths at age defined by the final parameter estimates are shown below (lengths are in cm and are evaluated at the mid-point of each age group):

Age group:	1	2	3	4	5	6	7	8	9	10	11	12
Average length:	25	36	45	53	59	65	70	75	78	81	84	89

The distribution of lengths at age (measured in mid-year) defined by the final parameter estimates is shown in Table 2.23.

Weights at length and maturity proportions at length defined by the final parameters are shown in Table 2.24, and selectivities at length defined by the final parameter estimates are shown in Table 2.25.

RESULTS

Definitions

The biomass estimates presented here will be defined in three ways: 1) age 3+ biomass, consisting of the biomass of all fish aged three years or greater in January of a given year (vector *b* in Appendix); 2) spawning biomass, consisting of the biomass of all spawning females in March of a given year (vector *c* in Appendix); and 3) survey biomass, consisting of the biomass of all fish that the Model estimates should have been observed by the survey in July of a given year (vector *d* in Appendix). The recruitment estimates presented here will be defined as numbers of age 3 fish in January of a given year (note that this is different from the recruitment parameter R_y, which represents numbers at age 1 in January of year *y*). The fishing mortality rates presented here will be defined as full-selection, instantaneous fishing mortality rates expressed on a per annum scale.

Biomass

Model 1's description of the recent history of the stock is shown in Table 2.26, together with estimates provided in last year's final SAFE report (Thompson et al. 1997). The biomass trends estimated in the present assessment are also shown in Figure 2.6. In both last year's and this year's assessments, the age 3+ biomass trend shows an increase during the early 1980s followed by a period of sustained high abundance throughout the rest of that decade, followed by a steady decline through 1997. The present assessment, however, indicates a slight upturn in age 3+ biomass for 1998.

Roughly paralleling the estimated age 3+ biomass trend, the model's estimated spawning and survey biomass levels show declines throughout the past decade. The model's estimate of 1998 spawning biomass is the lowest in the time series since 1979.

Recruitment

Model 1's estimated time series of age 3 recruitments is shown in Table 2.27, together with the estimates provided in last year's final SAFE report (Thompson et al. 1997). The current time series has a mean value of 152 million fish and shows only a moderate degree of variability, with an estimated coefficient of variation (assuming a lognormal distribution) of 37%.

One possible means of assigning a qualitative ranking to each year class within this time series is as follows: an “above average” year class can be defined as one in which numbers at age 3 are at least 120% of the mean, an “average” year class can be defined as one in which numbers at age 3 are less than 120% of the mean but at least 80% of the mean, and a “below average” year class can be defined as one in which numbers at age 3 are less than 80% of the mean. These criteria give the following classification of year class strengths:

Above average:	1977	1984	1987	1989	1995				
Average:	1976	1979	1980	1981	1982	1983	1985	1988	1990
Below average:	1975	1978	1986	1991	1992	1993	1994		

With the addition of the above-average 1995 year class, the average estimated recruitment level has shifted upward from the value reported in last year’s assessment (Thompson et al. 1997), and consequently the rankings of three years classes (1978, 1979, and 1980) have dropped by 1 level each. Other than these three year classes, however, the above results are identical to those presented in last year's assessment. The addition of the above-average 1995 year class also means that the run of consecutive below-average year classes that began with the 1991 cohort appears to have come to an end. However, it should be noted that the estimated strength of the 1995 year class is based largely on the 1996 survey, which observed this cohort at age 1. The contribution of the 1995 year class to the 1998 commercial fishery at age 3 was still fairly small, as selectivities for fish of this age are typically less than 10%. The model’s estimates of age 1 recruitment for 1997 and 1998 should not be taken too seriously, as these are based entirely on data from the commercial fisheries, where selectivities on ages 1 and 2 are close to zero.

Exploitation

Model 1’s estimated time series of the ratio between catch and age 3+ biomass is shown in Table 2.28, together with the estimates provided in last year’s final SAFE report (Thompson et al. 1997). The average value of this ratio over the entire time series is about 0.05. The estimated values exceed the average for every year after 1989, whereas the estimated values fall below the average for every year prior to 1990.

PROJECTIONS AND HARVEST ALTERNATIVES

Allocation of Fishing Mortality Between Gear Types

For the purpose of making projections and equilibrium calculations, total fishing mortality was apportioned between gear types (early trawl, late trawl, longline, and pot) at a ratio of 515:52:138:295. These proportions result in a mix of fishing mortality that matches the recent (1995-1997) average distribution of catches between the trawl and fixed-gear fisheries, between the early and late trawl fisheries, and between the longline and pot fisheries.

Reference Points Defined in Terms of Spawning Per Recruit

Reliable estimates of maximum sustainable yield (MSY), the equilibrium fishing mortality rate at MSY, and the equilibrium spawning biomass level at MSY are currently not available for the Pacific cod stock in the GOA. However, it is possible to estimate various reference points relating to equilibrium levels of spawning per recruit (SPR). The fishing mortality rate corresponding to three traditional SPR reference points are shown below, where the notation "$F_{SPR\%}$" denotes the fishing mortality rate that reduces the level of equilibrium SPR to a specified percentage of the pristine (i.e., equilibrium unfished) level:

Strategy:	$F_{40\%}$	$F_{35\%}$	$F_{30\%}$
F value:	0.35	0.43	0.52

Assuming an equilibrium recruitment equal to the historic average level (i.e., the arithmetic mean of all estimated recruitments in the time series), it is possible to estimate equilibrium stock sizes under various fishing mortality rates. For example, in the case of a zero fishing mortality rate, the equilibrium age 3+ biomass is estimated at a value of 997,000 t. In terms of spawning biomass, the estimate is 250,000 t. Another potentially useful reference point is the equilibrium stock biomass that would result from fishing at the $F_{40\%}$ rate under the assumption that recruitment is constant at the historic average level. This stock size is 610,000 t measured as age 3+ biomass and 100,000 t measured as spawning biomass. The equilibrium spawning stock size obtained under an $F_{40\%}$ harvest rate is denoted $B_{40\%}$.

Amendment 44 Requirements

Amendment 44 to the Fishery Management Plan for the Groundfish Fishery of the Gulf of Alaska defines the "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC (F_{ABC}). Because reliable estimates of MSY-related reference points are currently not available but reliable estimates of SPR-related reference points are available, Pacific cod in the GOA are managed under Tier 3 of Amendment 44. The following formulae apply under Tier 3:

3a) *Stock status:* $B/B_{40\%} > 1$
$F_{OFL} = F_{30\%}$
$F_{ABC} \# F_{40\%}$
3b) *Stock status:* $1/20 < B/B_{40\%} \# 1$
$F_{OFL} = F_{30\%} \times (B/B_{40\%} - 1/20) \times 20/19$
$F_{ABC} \# F_{40\%} \times (B/B_{40\%} - 1/20) \times 20/19$
3c) *Stock status:* $B/B_{40\%} \# 1/20$
$F_{OFL} = 0$
$F_{ABC} = 0$

The ratio of next year's spawning biomass to $B_{40\%}$ is the key to determining the sub-tier under which a stock is to be managed. In the case of Pacific cod, spawning biomass is measured in March, the month of peak spawning. Therefore, the estimate of next year's spawning biomass level is conditional on next year's fishing mortality rate. For example, if the Pacific cod stock were exploited next year at a fishing mortality rate equal to $F_{30\%}$, the estimate of next year's spawning biomass would be 127,000 t, above the corresponding $B_{40\%}$ value of 100,000 t. The ratio of these two values (1.27) is sufficient to determine that GOA Pacific cod should be managed under Tier 3a, because computing next year's spawning biomass under any lower fishing mortality rate would give a ratio at least as high. For purposes of comparison, however, it may be noted that the estimate of next year's spawning biomass under a fishing mortality rate equal to $F_{40\%}$ is 130,000 t.

Alternative Harvest Strategies

As discussed in the preceding section, harvest strategies of particular interest under Amendment 44 include $F_{30\%}$ and $F_{40\%}$. However, in terms of F_{ABC}, Amendment 44 establishes only a maximum permissible value, leaving open the question of what, if any, lower value(s) might also be of particular interest. For the past two years, the BSAI and GOA Pacific cod assessments have examined a harvest strategy that formally addresses uncertainty in two key parameters, *M* and *Q*. This strategy relies on the Bayesian meta-analysis described under the heading "Model Structure" above. Given the posterior distribution for *M* and *Q* derived in the meta-analysis, the next step was to profile the 1999 ABC obtained under an $F_{40\%}$ harvest strategy as a function of *M* and *Q*. The log-ABC profile was smoothed by fitting it to the following bivariate quadratic function:

$$\ln(ABC) = \beta_0 + \beta_{M1} M + \beta_{Q1} Q + \beta_{M2} M^2 + \beta_{Q2} Q^2 + \beta_{MQ} MQ \, .$$

The parameter estimates were as shown below, giving the relationship shown in the upper panel of Figure 2.7 (where the ranges of values along the *M* and *Q* axes represent plus or minus two standard deviations from the means of the respective marginal posterior distributions):

Parameter:	β_0	β_{M1}	β_{Q1}	β_{M2}	β_{Q2}	β_{MQ}
Value:	13.48	-1.617	-2.008	-0.319	0.320	0.811

Next, multiplying the posterior distribution by the above equation gives the weighted log-ABC profile shown in the lower panel of Figure 2.7. Taking the antilogarithm of the area under the curve gives the geometric mean ABC for 1999, which has a value of 90,900 t. The geometric mean was considered to be the risk-averse optimum in the previous two assessments. Under Model 1, a 1999 catch of 90,900 t corresponds to a fishing mortality rate of about 0.33, which translates into a relative equilibrium SPR level of 41.4%.

Recruitment Scenarios and Five-Year Projections

The projected 1999 catch and spawning biomass levels described above are essentially independent of the level of age 1 recruitment assumed for 1999 because age 1 fish have almost negligible weight, are completely immature, and have selectivities approximating zero for all commercial gear types. However, catch and spawning biomass projections beyond 1999 do depend on the level of age 1 recruitment assumed. To understand the sensitivity of catch projections to the recruitment assumption, four recruitment scenarios are examined in this assessment. Each scenario holds recruitment constant at some mean level. The scenarios differ only in terms of the type of mean (arithmetic or geometric) and the range of years (most recent 10 years or the entire 21-year time series) used in the computation. These are described in the table below:

Scenario:	1	2	3	4
Mean:	Arithmetic	Arithmetic	Geometric	Geometric
Horizon:	Short-term (10-year)	Long-term (21-year)	Short-term (10-year)	Long-term (21-year)
Recruits:	244,000,000	302,000,000	114,000,000	202,000,000

Given alternative harvest strategies corresponding to relative equilibrium SPR levels of 30%, 35%, 40%, and 41.4% and the four alternative recruitment scenarios listed in the table above, five-year projections of age 3+ biomass, spawning biomass, and catch were made. These are shown in Tables 2.29, 2.30, 2.31, and 2.32 for recruitment scenarios 1, 2, 3, and 4, respectively. Overall, these projections indicate that further declines in the GOA Pacific cod stock can be expected, even under a conservative exploitation strategy. However, it should be stressed that these projections are all based on constant recruitment assumptions, and could prove in retrospect to be either overly pessimistic or overly optimistic depending on the level of future recruitment that actually occurs. In particular, because the recruitment scenarios described above pertain only to *future* recruitment, all of the projections rely on the present assessment's estimates of age 1 recruitment from the 1996 and 1997 year classes, estimates which should be viewed as highly tentative at best.

ABC Recommendation

For 1998, the Council set the ABC at 77,900 t, which corresponded to the geometric mean catch projected in last year's assessment under an $F_{40\%}$ harvest strategy. The same strategy is recommended for use in setting the 1999 ABC. For 1999, the geometric mean catch under an $F_{40\%}$ harvest strategy is 90,900 t. Under Model 1, this corresponds to a fishing mortality rate of 0.33. A 1999 catch of 90,900 t would be approximately 3% below the maximum permissible level under Amendment 44 (93,900 t), a reduction which is warranted on the basis of the Bayesian meta-analysis described under the heading "Alternative Harvest Strategies" above.

Other methods for computing a prudent, uncertainty-motivated reduction from the maximum permissible ABC level could also be considered. For example, the 1996 ABC for GOA Pacific cod was determined by choosing the minimum $F_{40\%}$ catch located on the boundary of the 95% confidence interval for M, where the likelihood function was used as the basis for defining the confidence interval. From the information described under the heading "Model Evaluation" above, it can be shown that the minimum $F_{40\%}$ catch located on the boundary of the 95% confidence ellipse for the parameters M and Q is as follows, depending on which distribution is used as the basis for defining the confidence ellipse: 1) 53,300 t, using the prior distribution; 2) 31,100 t, using the likelihood function; and 3) 50,200 t, using the posterior distribution.

Another possible method of adjusting the maximum permissible ABC to account for uncertainty was suggested by the SSC at its October, 1998 meeting. The SSC suggested averaging the point estimates of the maximum permissible ABC under Models 1 and 2, with the point estimates from those two models providing a range. As already noted, the point estimate of the maximum permissible ABC for 1999 under Model 1 is 93,900 t. Under Model 2, the point estimate of the $F_{40\%}$ catch for 1999 is 36,400 t. However, under Model 2, the ratio of projected spawning biomass to $B_{40\%}$ is fairly low, and the maximum permissible ABC for 1999 is only 26,100 t. Thus, the 1999 ABC computed under the SSC's formula would be approximately 60,000 t, with a range of 26,100-93,900 t.

OTHER CONSIDERATIONS

The prey and predators of Pacific cod have been described or reviewed by Albers and Anderson (1985), Livingston (1989, 1991), and Westrheim (1996). In terms of percent occurrence, the most important items in the diet of Pacific cod in the BSAI and GOA are polychaetes, amphipods, and crangonid shrimp. In terms of numbers of individual organisms consumed, the most important dietary items are euphausids, miscellaneous fishes, and amphipods. In terms of weight of organisms consumed, the most important dietary items are walleye pollock, fishery offal, and yellowfin sole. Small Pacific cod feed mostly on invertebrates, while large Pacific cod are mainly piscivorous. Predators of Pacific cod include halibut, salmon shark, northern fur seals, sea lions, harbor porpoises, various whale species, and tufted puffin.

The above qualitative description of Pacific cod's trophic relationships notwithstanding, to date it has not been possible to incorporate ecosystem interactions into the model used to assess the Pacific cod stock. No recommendations regarding adjustment of the Pacific cod ABC on the basis of ecosystem considerations are made at this time.

SUMMARY

The major results of the Pacific cod stock assessment are summarized in Table 2.33.

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Table 2.1--Summary of catches (t) of Pacific cod by fleet sector and gear type. All catches since 1980 include discards. Jt. Vent. = joint venture. Catches for 1998 are through August.

Year	Fleet Sector			Gear Type				Total
	Foreign	Jt. Vent.	Domestic	Trawl	Longline	Pot	Other	
1978	11370	7	813	4547	6800	0	843	12190
1979	13173	711	1020	3629	9545	0	1730	14904
1980	34245	466	634	6464	27780	0	1101	35345
1981	34969	58	1104	10484	25472	0	175	36131
1982	26937	193	2335	6679	22667	0	119	29465
1983	29777	2426	4337	9512	26756	0	272	36540
1984	15896	4649	3353	8805	14844	0	249	23898
1985	9086	2266	3076	4876	9411	2	139	14428
1986	15211	1357	8444	6850	17619	141	402	25012
1987	0	1978	30961	22486	8261	642	1550	32939
1988	0	1661	32141	27145	3933	1422	1302	33802
1989	0	0	43293	37637	3662	376	1618	43293
1990	0	0	72517	59188	5919	5661	1749	72517
1991	0	0	76977	58091	7630	10464	792	76977
1992	0	0	80100	54305	15467	9984	344	80100
1993	0	0	56487	37806	8962	9707	12	56487
1994	0	0	47384	31446	6778	9160	0	47384
1995	0	0	69060	41877	11054	16050	79	69060
1996	0	0	68280	45991	10195	12041	53	68280
1997	0	0	77160	48405	10977	16416	1361	77160
1998	0	0	68174	38410	9719	18688	1358	68175

Table 2.2--History of Pacific cod ABC, TAC, total catch, and type of stock assessment model used to recommend ABC. ABC was not used in management of GOA groundfish prior to 1986. Catch for 1998 is current through August 30. The values in the column labeled "TAC" correspond to "optimum yield" for the years 1980-1986, "target quota" for the year 1987, and true TAC for the years 1988-1998.

Year	ABC	TAC	Catch	Stock Assessment Model
1980	n/a	60000	35345	n/a
1981	n/a	70000	36131	n/a
1982	n/a	60000	29465	n/a
1983	n/a	60000	36540	n/a
1984	n/a	60000	23898	n/a
1985	n/a	60000	14428	n/a
1986	136000	75000	25012	survey biomass
1987	125000	50000	32939	survey biomass
1988	99000	80000	33802	survey biomass
1989	71200	71200	43293	stock reduction analysis
1990	90000	90000	72517	stock reduction analysis
1991	77900	77900	76977	stock reduction analysis
1992	63500	63500	80100	stock reduction analysis
1993	56700	56700	56487	stock reduction analysis
1994	50400	50400	47384	stock reduction analysis
1995	69200	69200	69060	length-structured Synthesis model
1996	65000	65000	68280	length-structured Synthesis model
1997	81500	69115	77160	length-structured Synthesis model
1998	77900	66060	68175	length-structured Synthesis model

Table 2.3--Species ("Spe") discards in the 1996 Pacific cod fisheries, expressed as percentages of the total catch of all species in those fisheries. All species whose discards comprised at least one percent of the total catch in a given fishery are shown. For example, the entries "MG" and "6.5" near the top of the list under "Eastern Bering Sea" and "Longline" mean that discards of "miscellaneous groundfish" comprised 6.5% of the total catch of all species in the EBS longline fishery for Pacific cod in 1996.

Eastern Bering Sea						Aleutian Islands Region						Gulf of Alaska					
Longline		Pot		Trawl		Longline		Pot		Trawl		Longline		Pot		Trawl	
Spe	%	Spe	%	Spe	%	Spe	%	Spe	%	Spe	%	Spe	%	Spe	%	Spe	%
MG	6.5	MG	1.6	WP	18.9	PC	6.6	PC	1.9	AM	3.8	MG	3.4	MG	1.0	AF	2.8
PC	2.8	PC	1.4	RS	8.0	MG	5.8	MG	1.8	PC	2.6	PC	1.9			WP	2.3
WP	2.5			MG	3.3					RS	1.3					PC	1.8
AF	1.8			AF	3.2					SN	1.1						
				PC	2.9												
				FS	2.5												
				YS	1.3												

Key:

AF = arrowtooth flounder
AM = Atka mackerel
FS = flathead sole
MG = miscellaneous groundfish
PC = Pacific cod
RS = rock sole
SN = sharpchin/northern rockfish
WP = walleye pollock
YS = yellowfin sole

Table 2.4--Discards of Pacific cod in the 1996 fisheries, expressed as percentages of the total area-wide Pacific cod catch. All fisheries in which Pacific cod discards comprised at least one percent of the total area-wide Pacific cod catch are shown. For example, the entries "WP," "TWL-M," and "2.8" near the top of the list under "Eastern Bering Sea" mean that Pacific cod discards in the midwater trawl fishery for walleye pollock comprised 2.8% of the total Pacific cod catch from all EBS fisheries in 1996.

Eastern Bering Sea			Aleutian Islands Region			Gulf of Alaska		
Target	Gear	%	Target	Gear	%	Target	Gear	%
WP	TWL-M	2.8	AM	TWL	6.8	SF	TWL	4.4
YS	TWL	2.1	PC	LGL	1.3	AF	TWL	1.9
WP	TWL-B	2.1	PC	TWL	1.1	FS	TWL	1.3
RS	TWL	1.6				PC	TWL	1.1
PC	TWL	1.4						
PC	LGL	1.4						

Key:

Target Fisheries	
AF	= arrowtooth flounder
AM	= Atka mackerel
FS	= flathead sole
PC	= Pacific cod
RS	= rock sole
SF	= shallow-water flatfish
WP	= walleye pollock
YS	= yellowfin sole

Gear Type	
LGL	= longline
TWL	= trawl
TWL-B	= bottom trawl
TWL-M	= midwater trawl

Table 2.5--Catch of Pacific cod by year, gear, and period as used in the stock assessment model. Jig catches have been merged with pot catches for 1997-1998. Catch for 1998 is complete through period 2.

Year	Trawl			Longline			Pot		
	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
1978	0	0	4547	0	0	6800	0	0	0
1979	0	0	3629	0	0	9545	0	0	0
1980	0	0	6464	0	0	27780	0	0	0
1981	387	3532	6565	10504	5312	9656	0	0	0
1982	1143	2041	3495	9912	2890	9865	0	0	0
1983	2861	2844	3807	10960	4651	11145	0	0	0
1984	3429	2008	3368	11840	425	2579	0	0	0
1985	2427	571	1878	9127	6	278	0	0	2
1986	2999	431	3420	15922	401	1296	5	59	77
1987	5377	7928	9181	5343	983	1935	219	141	282
1988	16021	6569	4555	2979	507	447	1081	23	318
1989	24614	12857	166	2378	356	928	241	103	32
1990	43279	7514	8395	5557	109	253	2577	1008	2076
1991	55976	631	1484	7239	324	67	9591	0	873
1992	51727	1140	1438	12636	628	2203	9641	13	330
1993	33632	2624	1550	8474	307	181	9689	18	0
1994	29152	1421	873	6678	48	52	8742	0	418
1995	38481	799	2597	10668	159	227	15415	43	592
1996	41450	3048	1493	9938	152	105	12014	27	0
1997	40727	1828	5850	10403	228	346	12601	2175	3002
1998	34797	3613	0	9547	171	0	16489	3557	0

Table 2.6--Pacific cod length sample sizes from the commercial fisheries.

Year	Trawl Fishery			Longline Fishery			Pot Fishery		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1978	0	0	634	0	0	18670	0	0	0
1979	0	0	0	0	0	14460	0	0	0
1980	0	0	783	0	0	18671	0	0	0
1981	0	0	461	0	0	19308	0	0	0
1982	0	0	1390	0	0	22856	0	0	0
1983	0	0	2896	0	0	127992	0	0	0
1984	0	0	1039	0	0	47485	0	0	0
1985	0	0	0	0	0	10141	0	0	0
1986	0	0	0	0	0	87304	0	0	0
1987	0	0	0	0	0	387	0	0	0
1988	0	0	0	0	0	2432	0	0	0
1989	660	0	312	0	0	0	0	0	0
1990	25396	10892	12025	9925	0	0	2783	2920	10711
1991	38514	0	131	12551	143	0	49453	139	0
1992	39683	0	2255	28817	577	3603	37177	664	5013
1993	26844	0	0	11748	0	0	20866	0	0
1994	12579	0	0	5201	0	0	16342	0	217
1995	26039	120	2402	24635	0	0	46625	0	1233
1996	17858	0	0	14706	0	0	35256	432	0
1997	22822	225	3746	7239	119	154	26880	252	1537
1998	28219	2247	0	7981	304	0	20920	292	0

Table 2.7–Number of Pacific cod lengths sampled in the pot fishery during 1997, partitioned by period (1=Jan-May, 2=Jun-Aug, 3=Sep-Dec), sampling source (Sea = NMFS observer stationed at sea, Shore = NMFS observer stationed on shore, AK = State of Alaska), and size bin.

Bin	Period 1				Period 2				Period 3			
	Sea	Shore	AK	Total	Sea	Shore	AK	Total	Sea	Shore	AK	Total
1	0	0	6	6	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	1	0	1	0	0	0	0	0	0	0	0
4	0	1	0	1	0	0	0	0	0	0	0	0
5	0	4	0	4	0	0	0	0	0	0	0	0
6	0	9	0	9	0	0	0	0	0	0	0	0
7	0	12	0	12	0	0	0	0	0	0	0	0
8	0	18	0	18	0	0	0	0	0	0	0	0
9	0	43	0	43	0	0	0	0	0	0	0	0
10	0	45	0	45	0	0	0	0	0	0	0	0
11	4	39	0	43	0	0	0	0	0	0	0	0
12	13	38	2	53	0	0	0	0	2	0	2	4
13	58	177	28	263	0	0	0	0	2	10	6	18
14	134	727	108	969	0	5	0	5	9	29	8	46
15	303	1950	590	2843	0	18	8	26	17	60	13	90
16	634	3914	1741	6289	0	58	26	84	97	111	20	228
17	1064	4390	2087	7541	0	51	31	82	158	241	41	440
18	1003	2912	1285	5200	0	21	17	38	147	210	33	390
19	556	1252	491	2299	0	4	5	9	62	112	32	206
20	184	423	143	750	0	1	4	5	12	41	11	64
21	51	156	61	268	0	0	2	2	18	9	2	29
22	25	82	44	151	0	0	1	1	11	5	0	16
23	8	27	15	50	0	0	0	0	3	2	0	5
24	5	5	9	19	0	0	0	0	0	1	0	1
25	1	2	0	3	0	0	0	0	0	0	0	0
Total	4043	16227	6610	26880	0	158	94	252	538	831	168	1537

Table 2.8–Number of Pacific cod lengths sampled in the 1998 pot fishery through the month of August, partitioned by period (1=Jan-May, 2=Jun-Aug), sampling source (Sea = NMFS observer stationed at sea, Shore = NMFS observer stationed on shore, AK = State of Alaska), and size bin.

Bin	Period 1				Period 2			
	Sea	Shore	AK	Total	Sea	Shore	AK	Total
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	1	1	0	2	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	1	1	0	0	0	0
11	10	4	0	14	0	0	0	0
12	10	3	3	16	0	0	0	0
13	131	58	15	204	1	0	0	1
14	407	189	77	673	3	6	0	9
15	706	438	174	1318	14	17	0	31
16	2137	1042	570	3749	19	32	0	51
17	2938	1426	829	5193	26	34	0	60
18	2677	1329	566	4572	31	33	0	64
19	2014	889	259	3162	24	14	0	38
20	881	353	98	1332	8	7	0	15
21	306	119	41	466	8	3	0	11
22	114	26	16	156	6	1	0	7
23	30	7	11	48	3	0	0	3
24	11	0	1	12	1	0	0	1
25	2	0	0	2	0	1	0	1
Total	12375	5884	2661	20920	144	148	0	292

Table 2.9–Number of Pacific cod lengths sampled in 1996, partitioned by gear (trawl, longline, pot), location (at sea or on shore), period (1=Jan-May, 2=Jun-Aug, 3=Sep-Dec), and area (see Figure 2.4).

Per.	Area	Trawl			Longline			Pot			Total
		Sea	Shore	Subtot.	Sea	Shore	Subtot.	Sea	Shore	Subtot.	
1	610	3109	849	3958	2786	516	3302	1281	4238	5519	12779
1	620	3963	3318	7281	476	152	628	61	563	624	8533
1	621	0	1013	1013	789	110	899	2394	4410	6804	8716
1	630	10786	14686	25472	935	8363	9298	4915	13202	18117	52887
1	631	0	311	311	0	888	888	535	3961	4496	5695
1	639	0	0	0	0	0	0	332	0	332	332
1	640	0	0	0	0	0	0	616	51	667	667
1	All	17858	20177	38035	4986	10029	15015	10134	26425	36559	89609
2	610	0	0	0	0	0	0	308	124	432	432
2	All	0	0	0	0	0	0	308	124	432	432
3	620	0	0	0	17	0	17	0	0	0	17
3	All	0	0	0	17	0	17	0	0	0	17
Total		17858	20177	38035	5003	10029	15032	10442	26549	36991	90058

Table 2.10–Number of Pacific cod lengths sampled in 1997, partitioned by gear (trawl, longline, pot), location (at sea or on shore), period (1=Jan-May, 2=Jun-Aug, 3=Sep-Dec), and area (see Figure 2.4).

Per.	Area	Trawl			Longline			Pot			Total
		Sea	Shore	Subtot.	Sea	Shore	Subtot.	Sea	Shore	Subtot.	
1	610	5165	10752	15917	2390	0	2390	798	10318	11116	29423
1	620	1657	2543	4200	0	0	0	0	135	135	4335
1	621	909	417	1326	0	0	0	176	2093	2269	3595
1	630	14541	11978	26519	566	4518	5084	2608	6292	8900	40503
1	631	154	147	301	0	457	457	196	1385	1581	2339
1	639	0	0	0	0	0	0	115	0	115	115
1	640	0	0	0	0	0	0	0	185	185	185
1	649	0	0	0	0	153	153	0	187	187	340
1	All	22426	25837	48263	2956	5128	8084	3893	20595	24488	80835
2	610	0	0	0	0	0	0	0	158	158	158
2	630	225	0	225	119	0	119	0	0	0	344
2	All	225	0	225	119	0	119	0	158	158	502
3	610	0	0	0	0	0	0	538	489	1027	1027
3	620	0	0	0	0	0	0	0	186	186	186
3	621	25	0	25	0	0	0	0	0	0	25
3	630	3623	4968	8591	0	154	154	0	156	156	8901
3	631	98	0	98	0	0	0	0	0	0	98
3	All	3746	4968	8714	0	154	154	538	831	1369	10237
Total		26397	30805	57202	3075	5282	8357	4431	21584	26015	91574